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Design for a Concrete Arch

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DESIGN

FOR A

CONCRETE ARCH

...BY...

Philip Dakin Gillham

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE

IN CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE, 1904

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May 27, 1904 190

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

PHILIP DAKIN GILLHAM

ENTITLED DESIGN FOR A CONCRETE ARCH

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Civil Engineering.

Ira O. Baker

HEAD OF DEPARTMENT OF Civil Engineering

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Design for a Concrete Arch.

The problem to be discussed is the design for a concrete arch to cross the Boneyard Branch of Salt Fork creek, on Race Street, near the Wabash and Big Four railway tracks, in Urbana, Illinois.

The wooden bridge now in use is old and unsafe, and it has been proposed to replace it with a steel structure upon the old masonry abutments. However these abutments can not be repaired satisfactorily, and therefore the writer has designed in accordance with the elastic theory, a concrete arch applicable to this location.

The waterway required was found by investigating high water marks and the waterways of other bridges over the Boneyard Branch to be about 150 square feet. Railway tracks intersect the street at each end of the proposed arch, and limit the span to about 35 feet. The grade line of the top of the pavement is about 12 feet above the bottom of the creek. The soil is yellow

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clay, so that it is desirable to have the bottom of the abutments about 6 feet below the bottom of the creek.

The arch is to have a span of 32 feet and a rise of 8 feet, which gives the required waterway without an unallowable depth of backwater. The intrados used is a segment of a circle with a 20 foot radius. The thickness of the arch ring is 15 inches at the crown, and increases to 25 inches at the springing line. The vertical projection of any radial depth of the arch is 15 inches, the depth at the crown. The dimensions of the abutments, the end walls, and the wing walls can best be understood by examining the plates herewith.

The arch is to be covered with earth to a level 2 feet above the crown and above this with 1 foot of pavement and its foundation. The concrete is assumed to weigh 150 pounds per cubic foot, the earth filling 100 pounds per cubic foot, and the pavement 150 pounds per cubic foot. The above constitutes

the dead load. A uniform live load of 150 pounds per square foot is considered upon one half of the arch, to produce maximum stresses, when acting in addition to the dead load.

Analysis of Stresses.

The arch ring considered as an elastic curve beam fixed at both ends. The true line of resistance is determined and the stresses are figured on this assumption. The graphical method as outlined in Cain's Theory of Steel Concrete Arches is used. A section of the arch ring one foot wide is considered. The several steps in the analysis are outlined below, and the results of the work are stated either in the text following or in Tables I and II.

The several steps of the proposed solution, in order, are as follows: 1. The division of the neutral axis such that the quotient found by dividing the length of each section by its moment of inertia about its neutral axis

is constant (See Table I.). 2. The determination of the reduced load lines for the dead and live loads. 3. The passing of verticals through the center of each arch section, creating the areas #1, #2, #3, ... #24 (See Analysis Sheet, Plate 2.), the determining of the center of gravity of each area, and the computing the weights represented by each area. 4. Consider the several weights as forces acting vertically through the center of gravity of their respective areas, and assuming a trial pole distance, the trial force and equilibrium polygons are constructed. 5. By the method fully explained by Cain, the true pole distance is determined, and the true force and equilibrium polygons are drawn, and the graphical solution is checked algebraically. 6. The distance the line of resistance is above or below the neutral axis at the center of each arch section is determined, as is also the thrust, and from these the moment at these points is determined. 7. The stresses

are now computed by the formula: $S = \frac{T}{A} \pm \frac{Mv_1}{I}$, in which T is the normal component of the thrust, A the area of the section at the point considered, M the moment of the thrust about the neutral axis, v_1 the distance to the most remote fibre, and I the moment of inertia of the section about the neutral axis. The results of the computations, given in Table II, show that the unit compressive stress is about 100 pounds. The graphical analysis of the stresses in the arch is shown on the Analysis Sheet, Plate 2.

A complete solution of the problem would require the computation of the temperature stresses. The temperature stresses at a few critical points were determined under the assumption that the concrete when put into the forms, had a temperature of 53°F., and that the temperature might vary between +93°F. and -10F. With these assumptions the temperature stresses were computed according to Cain's method and were found to vary from 3/6 pounds compression per square

inch at the springing line to 223 pounds tension per square inch at the crown for a fall of 63°F. in temperature, and from 207 pounds tension per square inch at the springing line to 145 pounds compression per square inch at the crown for a rise of 40°F. in temperature. It does not seem probable that such stresses would actually occur, or many of the arches which are now standing would have failed. The range of temperature assumed is probably too large; but at present it is impossible to determine the relation which exists between the temperature of the atmosphere and the temperature of a mass of concrete whose exterior is exposed. For the case in question, if the concrete had a variation in temperature only one half as great as that of the atmosphere, the tensile stresses produced would still be much above a safe allowable limit. For the above reasons and because of lack of

available time, no attempt was made to redesign the arch and thereby reduce the stresses.

The complete design is shown on Plates #1, #3, and #4 and the analysis is shown on Plate #2. Plate #1 shows the cross section and dimensions of the arch ring and abutments and their location in reference to the grade line of the pavement. In Plate #2 the graphical determination of the stresses in the arch ring and abutments is shown. Plate #3 is the plan and elevation of the west end wall and abutments. Plate #4 is the plan and elevation of the east end wall, abutment, and a short retaining wall. A longitudinal section at the crown of the arch, showing the arch ring, the end walls, the earth filling and the pavement, is also given in this plate.

Estimate of Cost.

It will require 345 cubic yards

of concrete to construct this arch, exclusive of pavement foundations and side walks. When concrete composed of 1 part cement, 2 parts sand, and 4 parts coarse gravel or broken stone is used it should cost about $7.50 per cubic yard, including the removal of the old bridge and its foundations, the forms used in the construction of the arch, and the placing of the back filling. The pavement and the side walks between the two railway tracks include about 370 square yards and this should cost about $1.50 per square yard. The cost would then be $2587.50 for the arch, the abutments, and the walls and $555.00 for the pavement and side walks. Allowing $200.00 for engineering and inspection, the total cost to the city for the entire improvement would be $3342.50.

TABLE I.

LENGTH OF DIVISIONS OF NEUTRAL AXIS

NO. OF DIVISION	LENGTH OF DIVISION IN FEET.	RADIAL THICKNESS AT CENTER OF DIVISION IN FEET.
Springing line	——	2.08
S_1	3.93	1.87
S_2	2.55	1.62
S_3	1.99	1.49
S_4	1.70	1.42
S_5	1.53	1.37
S_6	1.40	1.33
S_7	1.31	1.30
S_8	1.28	1.29
S_9	1.25	1.28
S_{10}	1.22	1.27
S_{11}	1.18	1.26
Crown	——	1.25

Note:

Moment of inertia $= \frac{1}{12} b d^3$. $b = 1$ ft.

S/I = constant $= 12 \times .601 = 7.21$.

Length of neutral axis from springing line to crown of arch = 19.34 ft.

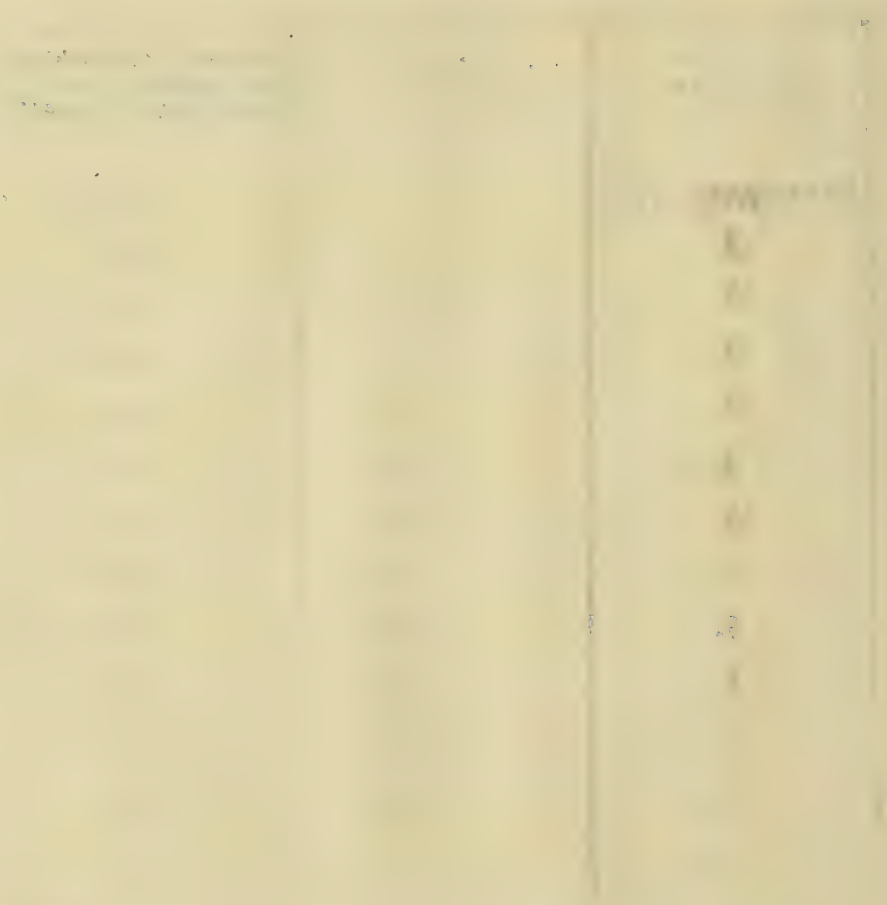


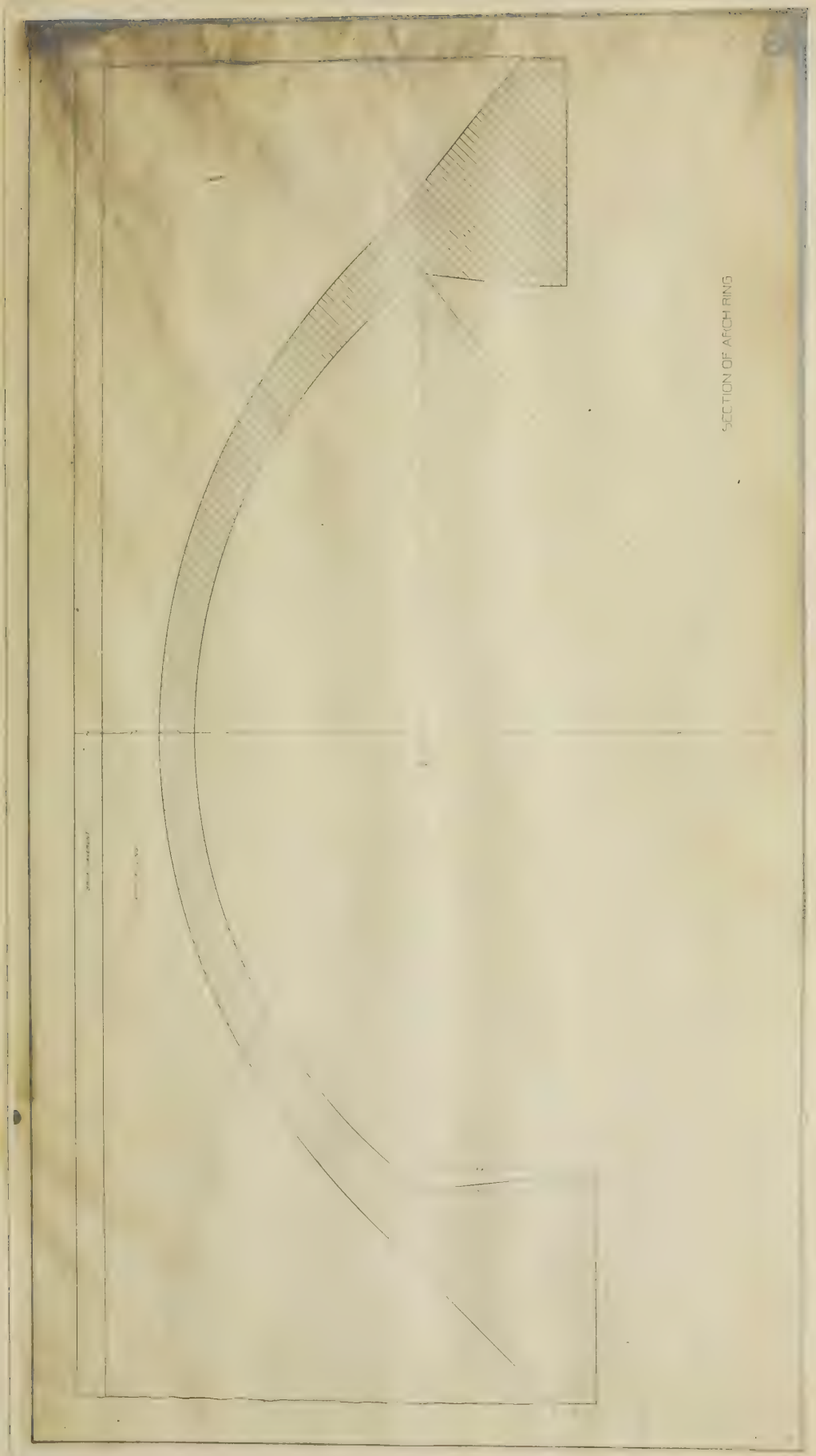
TABLE II

COMPUTATION OF STRESSES

SECTION	AREA IN SQ. FT.	THICKNESS IN FT.	MOMENT OF INERTIA	MOMENT ARM IN FT.	NOR. COMP. OF THRUST IN LBS.	MOMENT OF THRUST	MAX. AND MIN. STRESSES IN LBS. PER SQ. IN.	
							INTRODOS	EXTRODOS
	A	d	I	t	T	M = H × t.		
a_1	1.87	1.87	.53	+ .146	18400	1960	*42	89
a_2	1.62	1.62	.35	+ .064	16500	860	56	84
a_3	1.49	1.49	.28	+ .058	15500	760	58	86
a_4	1.42	1.42	.24	- .027	14900	360	80	65
a_5	1.37	1.37	.21	- .059	14450	790	92	57
a_6	1.33	1.33	.19	- .079	14100	960	94	53
a_7	1.30	1.30	.18	- .103	13900	1380	109	40
a_8	1.29	1.29	.18	- .095	13700	1270	103	46
a_9	1.28	1.28	.17	- .074	13600	990	102	51
a_{10}	1.27	1.27	.17	- .064	13500	860	100	52
a_{11}	1.26	1.26	.17	- .010	13450	130	78	71
a_{12}	1.26	1.26	.17	+ .012	13450	160	70	79
a_{13}	1.27	1.27	.17	+ .025	13500	330	65	83
a_{14}	1.28	1.28	.17	+ .053	13600	700	58	97
a_{15}	1.29	1.29	.18	+ .062	13700	830	53	98
a_{16}	1.30	1.30	.18	+ .068	13900	910	51	98
a_{17}	1.33	1.33	.19	+ .070	14200	940	50	99
a_{18}	1.37	1.37	.21	+ .084	14600	1120	48	100
a_{19}	1.42	1.42	.24	+ .063	15200	840	57	91
a_{20}	1.49	1.49	.28	+ .050	16000	670	62	87
a_{21}	1.62	1.62	.35	- .070	17200	940	89	58
a_{22}	1.87	1.87	.53	- .174	19500	2330	101	45

*All stresses are compression.

H = Pole distance = Horizontal projection of thrust at any point = 13400 lbs.


SECTION OF ARCH RING

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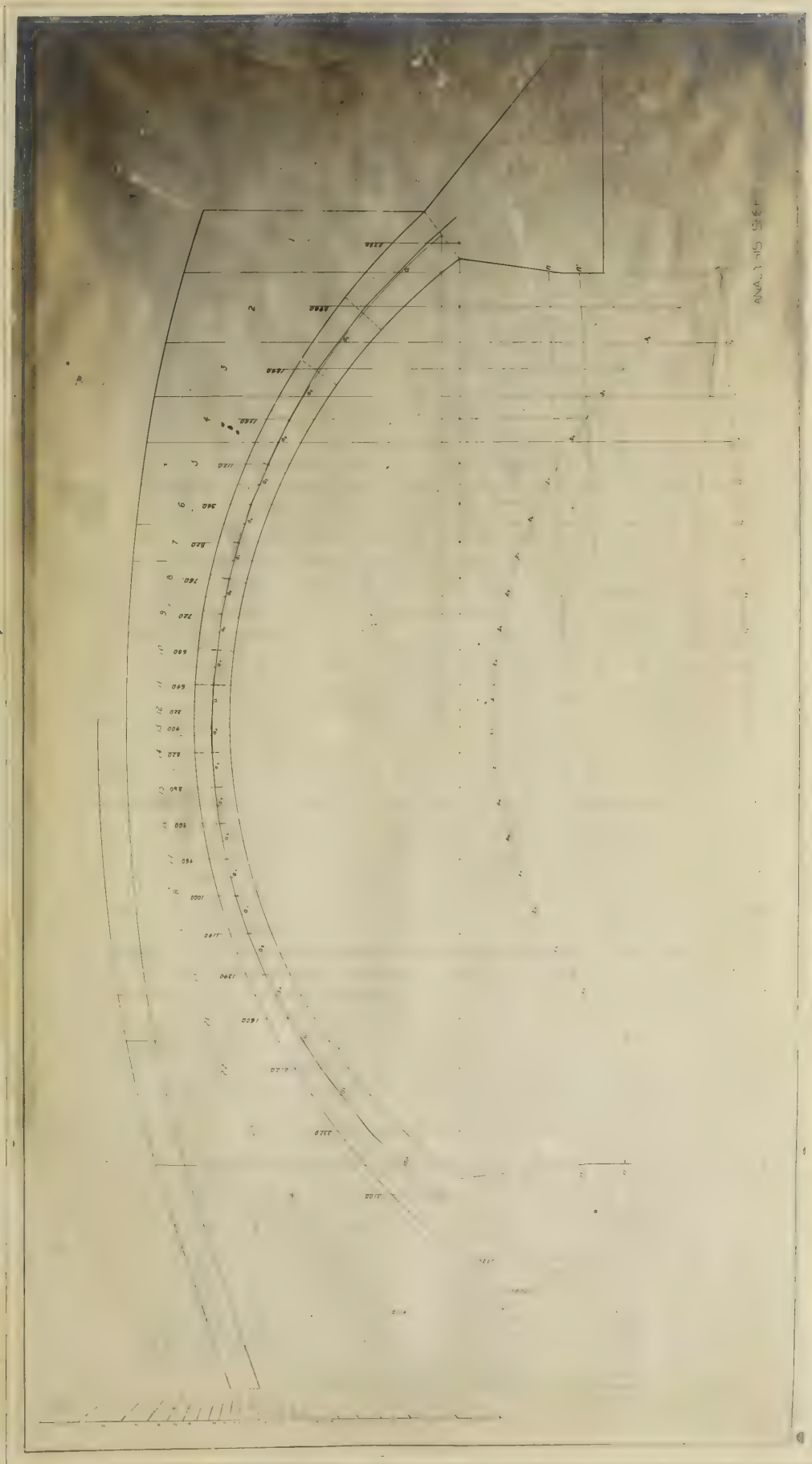
ANALYSIS SHEET

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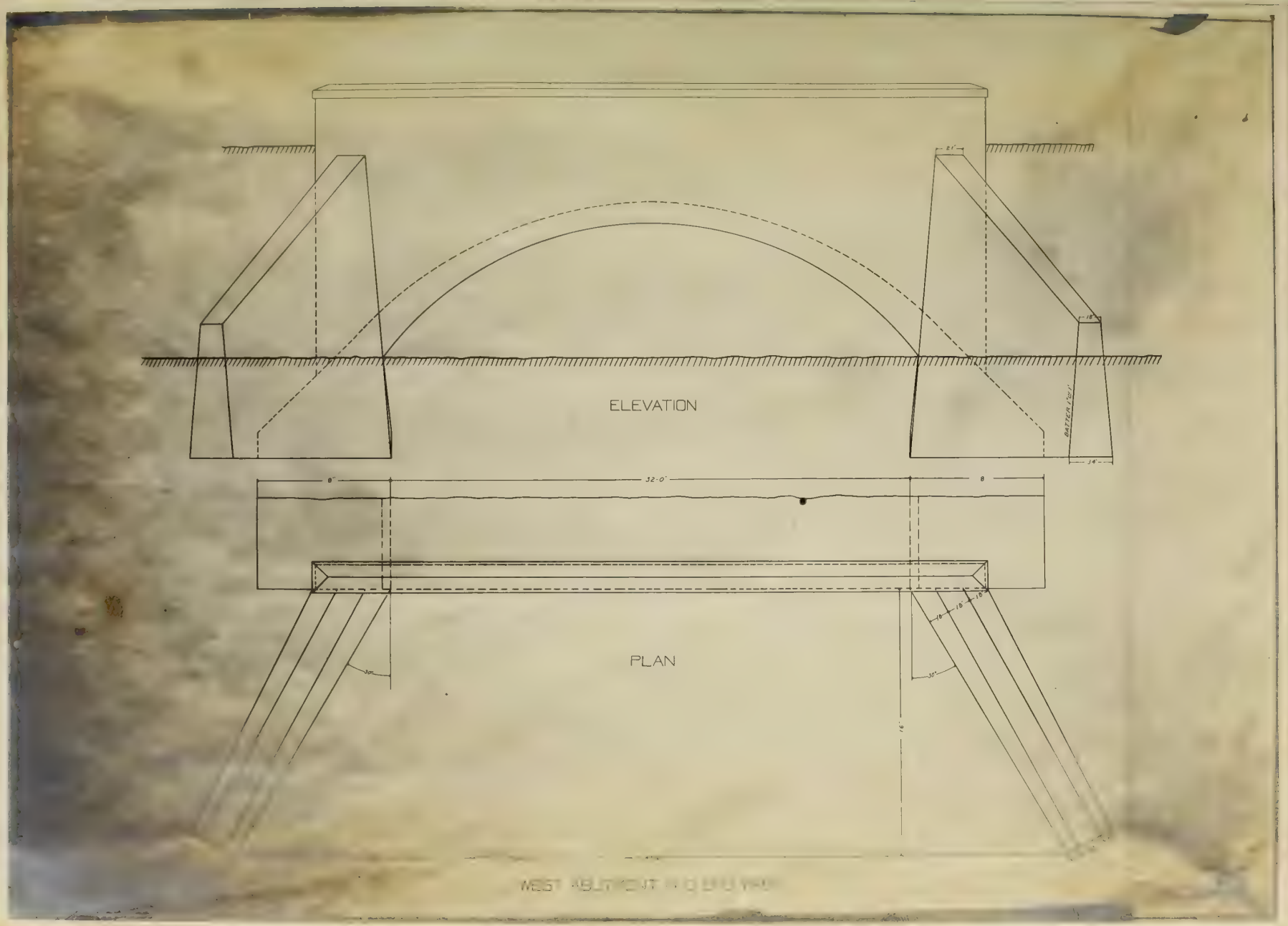
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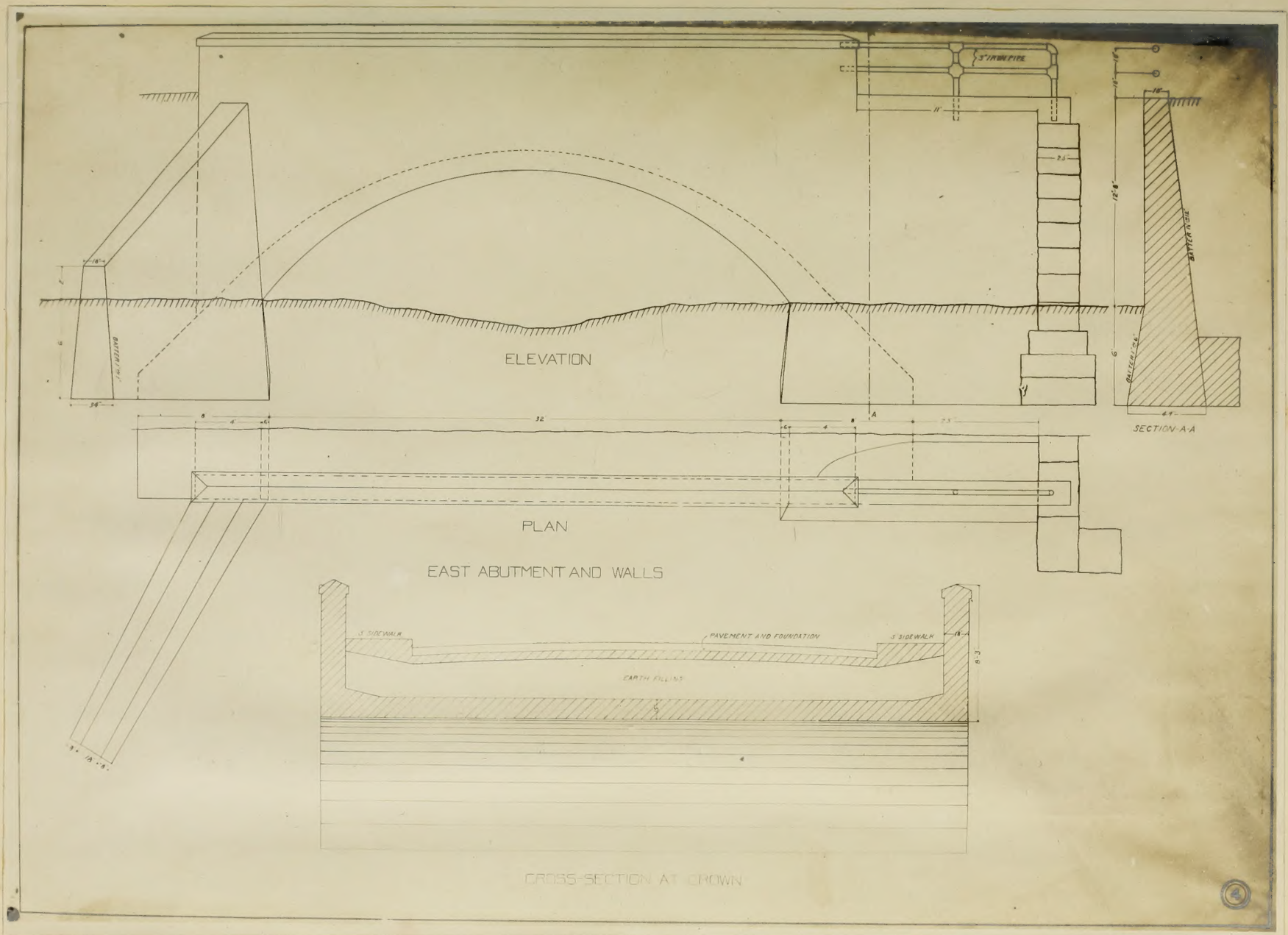
3" IRON PIPE
ELEVATION
SECTION A-A
PLAN
EAST ABUTMENT AND WALLS
5' SIDEWALK
PAVEMENT AND FOUNDATION
5' SIDEWALK
EARTH FILLING
CROSS-SECTION AT CROWN

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